Modeling Wind Wave Evolution from Deep to Shallow Water

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LONG-TERM GOALS

Ocean waves are an important aspect of upper ocean dynamics, in particular on the shallow continental shelves and in coastal areas. The long-term objective of this work is to advance modeling capability in such coastal areas by improving model representations of effects associated with nonlinearity, inhomogeneity, and dissipation.

OBJECTIVES

The specific objectives of the present work are 1) to develop and implement an efficient and scalable approximation for the nonlinear quadruplet source term, 2) to develop and implement a generalized nonlinear source term that is accurate in water of arbitrary depth, 3) to develop and implement an improved nonlinear closure for triad nonlinear interactions in shallow water, and 4) improve representations of dissipation by wave breaking and wave-bottom interactions in shoaling waves. This project is a collaboration with Tim Janssen and Gerbrant van Vledder (see also their annual report). My primary responsibility in this joint effort is the dissemination and analysis of field observations.

APPROACH

Modern, third-generation (3G) wave models are based on an action balance (or radiative transfer) equation, which describes the transport of wave energy (or action) through a slowly varying medium and time. In Lagrangian form (for convenience) this balance equation can be written as

$$\frac{dN(\mathbf{k})}{dt} = S_{in}(\mathbf{k}) + S_{ds}(\mathbf{k}) + S_{sc}(\mathbf{k}) + S_{nl}(\mathbf{k}) \qquad (1)$$

where $N(\mathbf{k})$ is the wave action at wavenumber vector $\mathbf{k}$ and t is time. The forcing terms on the right-hand side are referred to as source terms and account for the input of energy by the wind (S_{in}), spectral redistribution of energy through scattering by seafloor topography (S_{sc}) or through nonlinear wave-wave interactions (S_{nl}) , and dissipation of wave energy (S_{ds}) through e.g. breaking or bottom friction.

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In this study we will develop and improve the source terms for nonlinear interactions S_{nl} and energy dissipation S_{ds}, to account for effects of finite depth and shallow water, and to ensure a consistent and smooth model representation of wave evolution from deep to shallow water. In particular, we will develop an efficient method for the evaluation of the nonlinear source term, allowing for greater efficiency and accuracy in operational use. To allow modeling of wave propagation from deep to shallow water, we will modify the nonlinear source term to account for changes in relative water depth [Janssen *et al.* 2006], and develop an improved closure approximation for nearshore wave propagation [Janssen, 2006]. We will also develop and test improvements to wave dissipation parameterizations through detailed comparisons of model results to laboratory and field observations in a wide range of conditions.

We will analyze, prepare, and disseminate selected field experimental data sets, collected by the PI's, to the project teams for the purpose of validation and calibration of new model developments.

WORK COMPLETED

We have disseminated the ONR NCEX (Nearshore Canyon Experiment) field observations to the NOPP teams. These observations are particularly well suited to validate model representation of refraction and wave focusing over extreme topography.

We have also completed a comprehensive analysis and quality control of a data set of wave propagation across the muddy Louisiana shelf (figure 1). This dataset will be shared with the NOPP teams and will provide a unique set of observations of wave propagation over mud and the effects of larger-scale circulation and sediment dynamics on coastal wave evolution. The analysis findings will contribute to understanding of dissipation over mud in operational wave models.

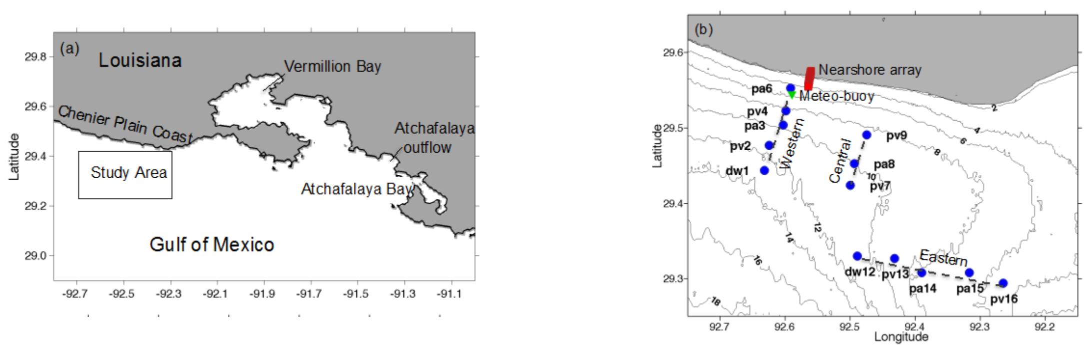

Figure 1 Overview of experimental area (left panel) and sensor locations (right panel, in blue) for the 2008 Louisiana Waves-over-Mud MURI experiment.

Analysis of the Louisiana data conducted by graduate student Anita Engelstad shows that the effects of mud on wave evolution can be time varying and episodic. During onshore swell conditions, the observations show, as expected, enhanced dissipation. However, an even more pronounced effect of the muddy bottom on wave evolution was seen during fetch-limited, wind-forced conditions. The presence of mud was seen to suppress wave growth during such conditions. From satellite observations (figure 2), the observed episodes of strong mud-induced effects on wave development were related to larger-scale plume dynamics originating in the Atchafalaya Bay system and extending westward into the research area during easterly wind conditions.

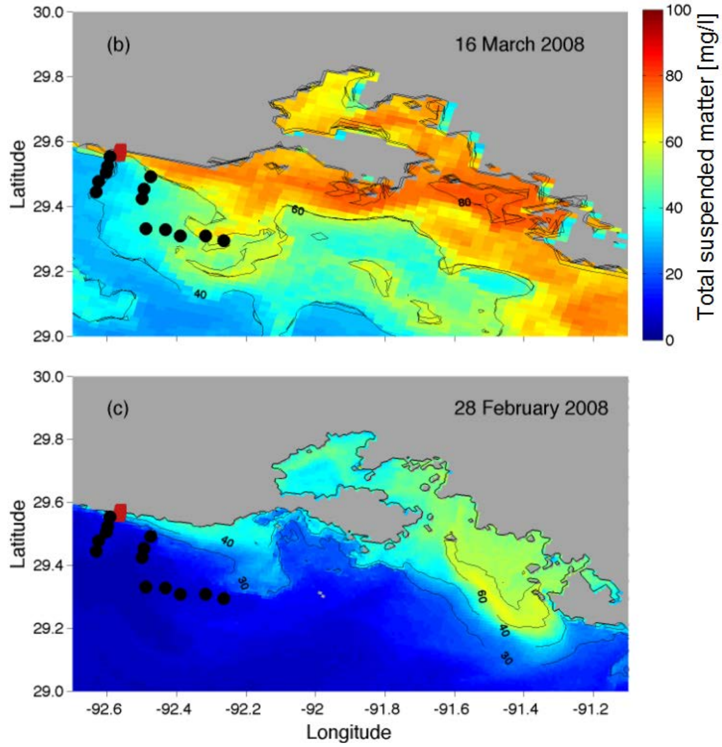

Figure 2 Estimate of total suspended-matter concentrations (from Modis 250 imagery) on (b) March 16, and (c) February 28. High concentrations are red, low concentrations are blue (color scale on right). Grey shading is land. Instrument locations are shown with black circles (shelf stations) and red squares (shoreward stations). The strong variability in sediment concentrations due to changes in wind are shown to strongly affect dissipation and wave growth characteristics in the experimental area.

RESULTS

To evaluate the performance of the bottom dissipation source term in SWAN on the muddy Louisiana shelf, we compared observed and predicted energy flux gradients (figure 3). Overall, the hindcast predictions of the magnitude and the spectral distribution of the flux gradients agree reasonably well with the observations (compare figure 3a with figure 3b and compare figure 3d with figure 3e), both offshore (h > 8 m) and nearshore (h < 4 m). The events characterized by large, negative flux gradients are associated with strong dissipation (mostly in the low-frequency band 0.04-0.20 Hz), and occur during times of high wave energy.

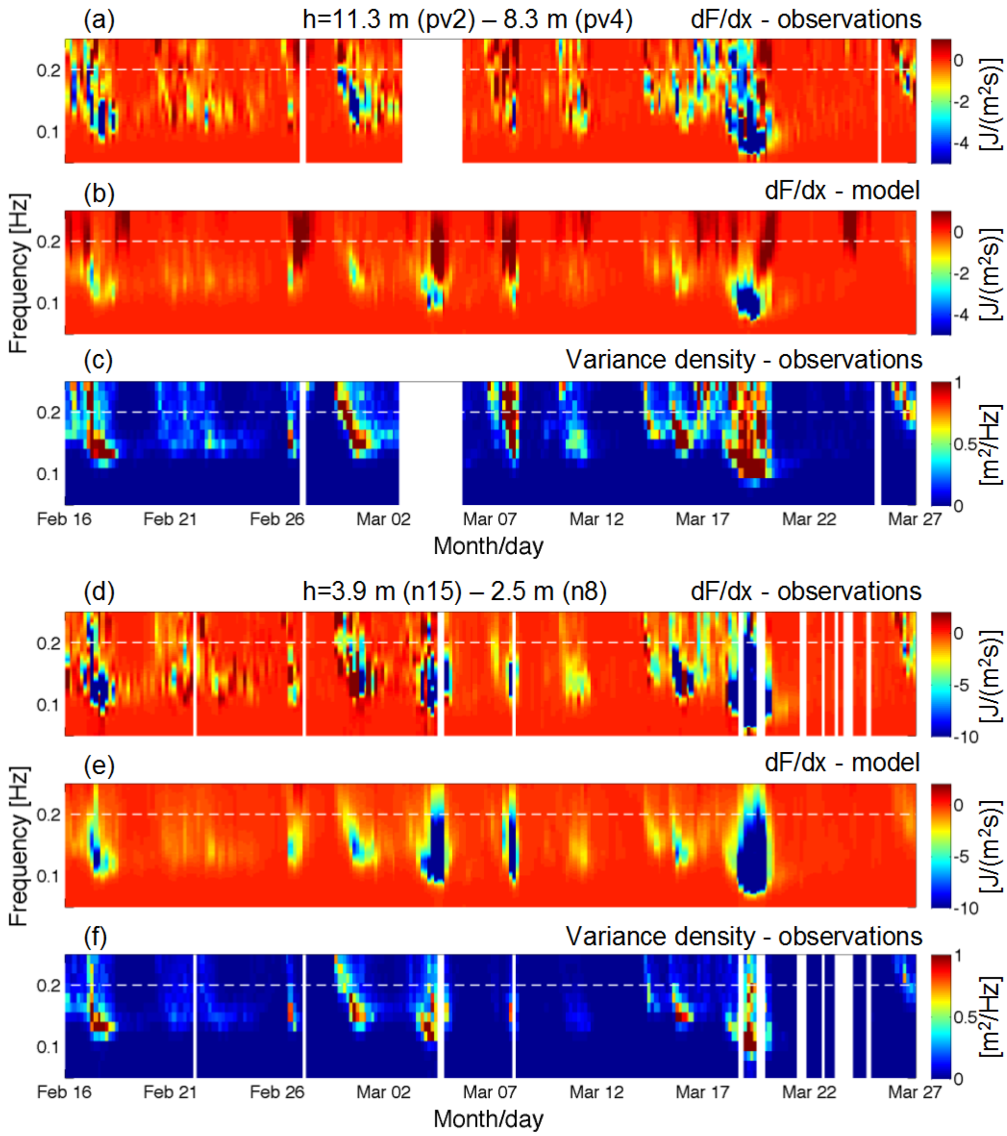

Figure 3 Contours (color scales on the right) of (a and d) observed energy flux gradients, (b and e) modeled (SWAN) energy flux gradients, and (c and f) observed energy density as a function of frequency and time. a-c are between 11.3 and 8.9 m depth and d-f are between 3.9 and 2.5 m depth. Positive flux gradients indicate generation, negative flux gradients indicate dissipation. Note the different scales of (a) and (b) versus (d) and (e).Louisiana Waves-over-Mud MURI experiment. (from Engelstad et al., 2012)

Differences between model and observations are most pronounced at higher frequencies (≥ 0.2 Hz), especially at the seaward stations (compare figure 3a with 3b), where the model does not reproduce the observed dissipation. In contrast with the observations that show either no growth (e.g. February 18, March 24 in figure 3a) or dissipation (around March 17 in figure 3a), the model predicts a number of wave growth events (positive energy flux gradients in figure 3b) where wind input dominates over dissipation.

Closer to shore, where dissipation rates usually are larger (and thus dominate over possible local generation), the model-data agreement in the spectral distribution is generally better (compare figure 3d with 3e).

IMPACT/APPLICATIONS

The model improvements developed and tested in this study will contribute to improvements in modeling capability of nearshore wave propagation in research and operational models. Efficient and accurate approximations for the four-wave interactions will improve prediction of spectral shapes in operational models. The development of general evolution equations for wave correlators form a basis for the development of a new class of stochastic models that include inhomogeneous and non-Gaussian statistics. In turn, improved modeling capability of wave dissipation, spectral evolution, and higher-order statistics such as skewness and asymmetry, will contribute to improvements in research and modeling of coastal circulation and transport processes.

RELATED PROJECTS

The development of transport equations for cross-correlations in random waves also contributes to the study of coastal wave-current interaction as part of the ONR Inlets and River Mouths DRI.

REFERENCES

Janssen, T. T., T.H.C. Herbers, and J. A. Battjes (2006) Generalized evolution equations for nonlinear surface gravity waves over two-dimensional topography, *J. Fluid Mech.* **552**, 393-418.

Janssen, T.T. (2006) Nonlinear surface waves over topography, *PhD dissertation*, Delft University of Technology, 208p

PUBLICATIONS

Engelstad, A., T.T. Janssen, T.H.C. Herbers, G. Ph. Van Vledder, S. Elgar, B. Raubenheimer, L.T. Trainor, and A. Garcia-Garcia, Wave evolution across the Louisiana shelf, *Cont. Shelf Res.*, 2012 [submitted, refereed]

Ardhuin, Fabrice and T. H. C. Herbers, Noise generation in the solid Earth, oceans, and atmosphere, from non-linear interacting surface gravity waves in finite depth, J. Fluid Mech., 2012. [submitted, refereed]